444-ANYS-0094
Revision (-)

Re-entry Survivability Analysis of the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX)

February, 2001

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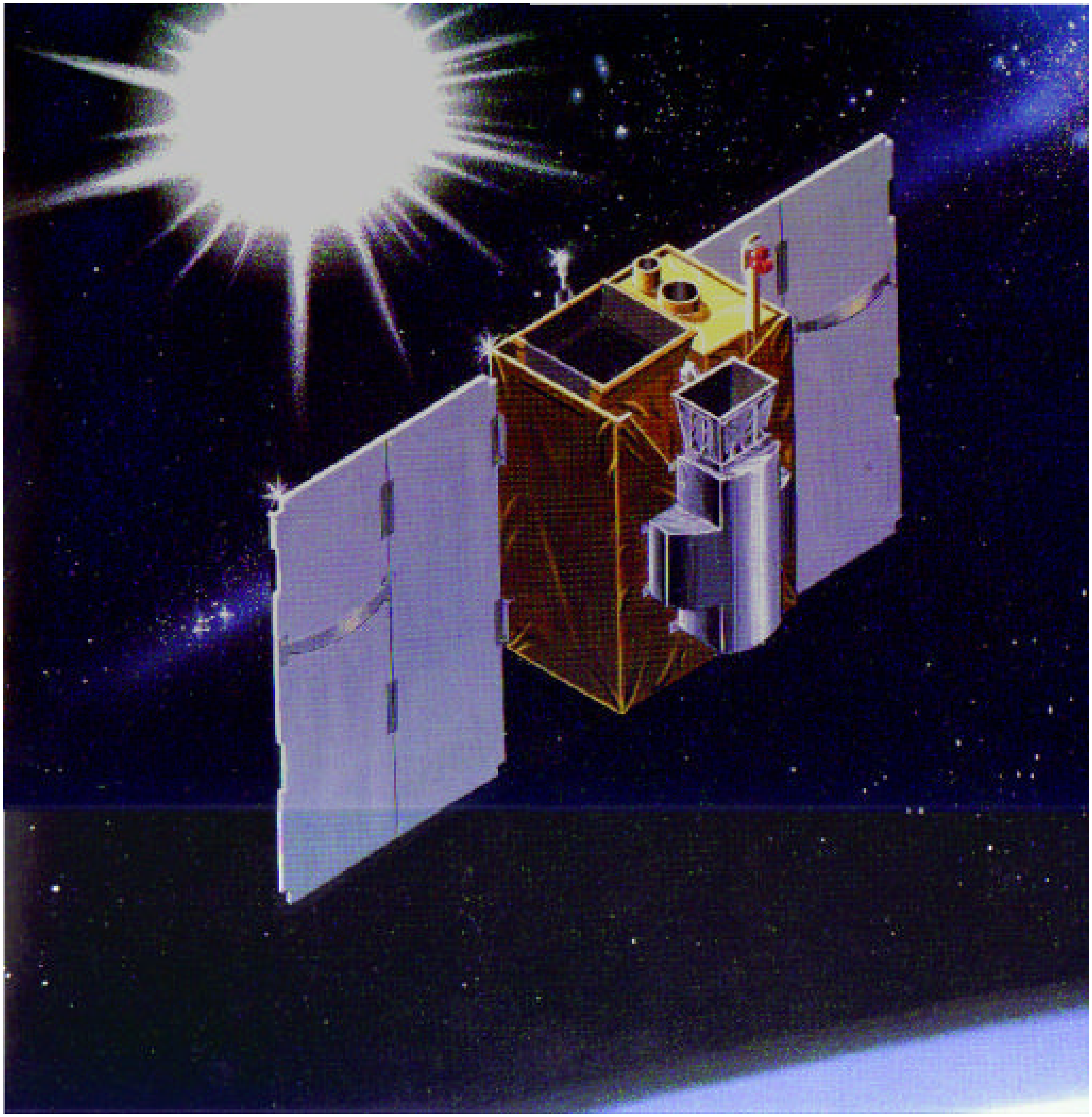

Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX)

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EXECUTIVE SUMMARY

A re-entry survivability analysis of components of the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) spacecraft was performed to assess the risk of significant debris resulting from an uncontrolled re-entry. SAMPEX does not have a propulsion system so a controlled re-entry is impossible. Flight dynamics analysis shows that SAMPEX's orbit is decaying and the nominal prediction is for re-entry into Earth's atmosphere between November 2008 and December 2011. This survivability analysis was performed in accordance with NASA Policy Directive, NPD 8710.3, "NASA Policy For Limiting Orbital Debris Generation" and NASA Safety Standard, NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris". Because the spacecraft is currently on-orbit, and no design changes are possible, it was only evaluated for compliance with Guideline number 7, "Survival of Debris from the Post Mission Disposal Atmospheric Re-entry Option". This analysis utilized Debris Analysis Software (DAS) Release 1.0, supplied through NASA's Orbital Debris Program Office at the Johnson Space Center (JSC). JSC is the NASA Lead Center for orbital debris research. This document describes the analysis method used for the breakup of SAMPEX, the assumptions and manipulations employed to model various resultant fragments and provides an estimate of the re-entry debris casualty area from those components predicted to survive re-entry. A total of 45 objects were modeled, with none predicted to survive. Analysis of the entire spacecraft re-entering intact resulted in a total debris casualty area of 1.44 square meters. This is well within the NSS 1740.14 Guideline number 7 upper limit of 8 square meters and represents a risk of 1 in 49,400 for causing a casualty within the ground track for SAMPEX which has a 82 degree orbital inclination.

1. INTRODUCTION

The Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) was launched July 3, 1992 into a 550 x 675 kilometer, 82° orbit. SAMPEX is one mission in NASA's Small Explorer (SMEX) program. The four SAMPEX intsruments are a complimentary set of high resolution, high sensitivity, particle detectors used to conduct studies of solar, anomalous, galactic, and magnetospheric energetic particles. The four instruments are the Low Energy Ion Composition Analyzer (LEICA), the Heavy Ion Large Telescope (HILT), the Mass Spectrometer Telescope (MAST), and the Proton/Electron Telescope (PET). The instrument hardware is integrated throughout the primary structure and consists of three sensor assemblies, an 8-bit instrument interface microprocessor, and a tank of isobutane for use by one of the sensors. The instrument weight totals 40 kilograms (88 pounds) and occupies most of the upper half of the spacecraft. The total spacecraft mass at launch was 161 kilograms (354 pounds).

Upon deployment from the Scout launch vehicle, SAMPEX used a yo-yo despin mechanism to achieve a stable attitude. The two despin weights and cables were then released from the spacecraft, and re-entered the atmosphere separately. The despin components were the only objects intentionally released as a part of normal mission operations.

SAMPEX is a momentum-biased, sun pointed spacecraft that maintains the experiment-view axis in a zenith direction as much as possible. The Attitude Control System (ACS) uses a combination of three orthogonal torque rods to react against the Earth's magnetic field and one reaction wheel to provide the bias momentum. A two-axis digital sun sensor, a three-axis magnetometer, and a set of five coarse sun sensors are used for attitude determination.

Two deployable, fixed solar arrays containing 1.7 m^2 of solar cells provide an orbit average power of 100 Watts to the spacecraft and intstruments. The data system for the SAMPEX mission contains 30 MB of memory. It utilizes a fiber optic MIL-STD-1773 data bus to connect the subsystems. Two hemispherical coverage quadrifilar helix antennas are used for ground communication.

The original mission duration was planned as one year, with a goal of three years. The spacecraft is still operational, over eight years after launch. Because SAMPEX uses no propulsion system, controlled re-entry is not an option. Re-entry is predicted between November 2008 and December 2011 due to atmospheric drag.

The basic methodology for this analysis follows the guidelines in NASA Safety Standard, NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris", in particular Guideline number 7, "Survival of Debris from the Post Mission Disposal Atmospheric Re-entry Option". For this analysis, the intact SAMPEX spacecraft was assumed to break up at an altitude of 78 km, which has been determined to be the approximate altitude at which most spacecraft structures begin to disintegrate. Below this altitude, various components and subcomponents were assumed to become free falling and were modeled individually. A detailed description of the modeling approach can be found in Section 2, Methods of Analysis.

The calculation of the demise altitudes and debris casualty area for the various items modeled was performed using NASA Orbital Debris Analysis Software (DAS) Version 1.0, developed by the Orbital Debris Program Office at the Johnson Space Center. DAS is an acceptable analysis tool per the NASA Safety Standard. More sophisticated, higher fidelity tools such as the ORSAT software are available to the JSC debris analysis group. Close correlation between the DAS results for EUVE and ORSAT calculations for similar objects on the Compton Gamma Ray Observatory (CGRO), provides confidence in the DAS results. Analyses for EUVE using both DAS and ORSAT showed DAS to be the most conservative approach yielding a debris area about twice that predicted by the ORSAT application.

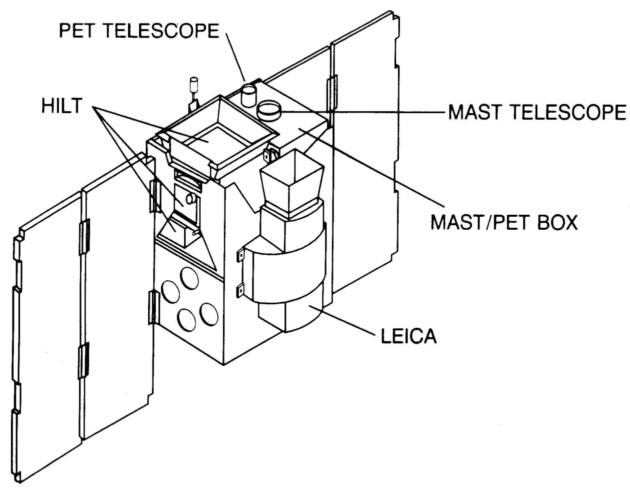

Figure 1. The SAMPEX spacecraft in its orbital configuration.

2. METHOD OF ANALYSIS

2.1 NASA REQUIREMENTS

2.1.1 NPD 8710.3, "NASA POLICY FOR LIMITING ORBITAL DEBRIS GENERATION"

NPD 8710.3 states that it is NASA policy to, "Conduct a formal assessment in accordance with NSS 1740.14, on each NASA program/project".

2.1.2 NSS 1740.14, "GUIDELINES AND ASSESSMENT PROCEDURES FOR LIMITING ORBITAL DEBRIS"

Section 7 of NSS 1740.14 contains the following Guideline:

> "7-1 *Limit the risk of human casualty:* If a space structure is to be disposed of by uncontrolled re-entry into the earth's atmosphere, the total debris casualty area for components and structural fragments surviving re-entry will not exceed 8 m^2. The total debris casualty area is a function of the number and size of components surviving re-entry and of the average size of a standing individual."

In the Method to Assess Compliance with the Guidelines for Section 7, it is stated:

1. "If the dimensions of the parent object are approximately equal in all directions, it should be modeled as a sphere with diameter, D, defined to be the largest dimension. … If the parent body is not modeled as a sphere, it should be modeled as an equivalent cylinder. The longest dimension will be the length (L), and the largest dimension in the transverse direction will be the diameter of the cylinder (D)."

This restricts the selection of modeling shapes to only spheres and cylinders, and further defines the dimensions which must be used for the equivalent shape model.

3. "If the parent body is larger than 0.5 m in any dimension and consists of multiple components, it will break up into components of significant size during re-entry. Each of these components must then be evaluated separately. The design of the structure must be reviewed and all components that are larger than 0.25 m in any dimension must be identified.

If the structure is smaller than 0.5 m in any dimension, the parent body is considered a single piece of reentering debris and step 4 [modeling individual components] may be skipped."

The Method description goes on to state that all objects identified as exceeding the dimensional requirement of 0.25 m must be modeled for re-entry debris. Notice that the actual verbage used in the NSS does not address those objects whose maximum dimension is 0.25 m or less, and thus leaves the analysis of them as optional. The second condition applies to the SAMPEX spacecraft itself, and the effect of this approach will be examined.

2.2 SOFTWARE

This analysis used NASA's Debris Analysis Software (DAS) version 1.0. DAS is a DOS based program that is configured to follow the structure of NSS 1740.14. In particular it is divided into options that correspond to the Guidelines sections in the NSS. This analysis was performed using the Guideline 7 option for uncontrolled re-entry debris.

DAS allows the modeling of objects as spheres, cylinders, boxes or plates only. This means that actual spacecraft fragments, which are rarely uniform in shape, require manipulation to be modeled as the closest equivalent to one of these shape options. Also, the NSS requires the modeling of objects only as either spheres or cylinders, so this was done for all SAMPEX components.

2.2.1 SOFTWARE LIMITATIONS

In addition, DAS cannot directly model the wall thickness of hollow objects such as electronic boxes. Manipulation of material properties can be used to compensate for this limitation, in accordance with a procedure recommended by the experts at JSC. The details of this approach (termed "Effective Density") are described in detail in Section 2.3.3 below.

2.2.2 SOFTWARE ERRORS

It has recently been discovered that version 1.0 of DAS contains an error in terms of the method for calculating the debris casualty area. Results show that this error is insignificant for the case of SAMPEX, so the results reported here will not be refigured consistent with the NSS. Another error in version 1.0 involves the thermal calculations specifically for boxes. Because this analysis used only spheres and cylinders, this error will be ignored. It has been reported that both of these errors have been corrected in the soon-to-be-released DAS version 1.5.

2.3 ASSUMPTIONS / PROCEDURES

2.3.1 OBJECT SELECTION

The SAMPEX spacecraft consists of several major structural components and numerous smaller items. The spacecraft was divided into components as identified in the SAMPEX Assembly Drawing (GD1499685). The overall dimensions of all objects were determined as accurately as possible, either from the existing spacecraft drawings or best estimations when the drawings could no longer be located. Object selection was based on the dimensions and the primary material the object was composed of. Electronic boxes were all assumed to be primarily aluminum. As directed by the NSS, all objects with a largest dimension greater than 0.25 m (approximately10 inches) were included in the analysis. In addition, all objects made primarily of metals other than aluminum and larger than 0.05 m (approximately 2 inches) were included.

Figures 2 through 4 show drawings of the complete SAMPEX spacecraft, which should be helpful in understanding references to spacecraft components in the next sections. Table 1 shows the spacecraft components which were identified, and notes which ones were included in the analysis. Special consideration was given to the battery assembly and the reaction wheel, since historically these are among the most common objects to survive re-entry.

Table 1: SAMPEX Components Identified from the Assembly Drawings

Spacecraft Subsystem	Component Name	Quantity	Drawing #	Mass (Kg)	Natural Material	Natural Shape	Width/ Diam.	Length (m)	Height (m)	Component Modeled?
ACS	ACE	1	1499912	4.30	Al 6061	Box	0.241	0.312	0.074	Yes
ACS	Coarse Sun Sensor	5		0.05	Aluminum	Cylinder	0.019	0.012		No
ACS	Digital Sun Sensor	1	40650	0.12	Al 6061	Box	0.081	0.081	0.020	No
ACS	Digital Sun Sensor Elect.	1	40590	0.70	Al 6061	Box	0.114	0.124	0.054	No
ACS	Magnetometer	1		0.07	Fiberglass	Irregular Box	0.044	0.057	0.031	No
ACS	Reaction Wheel	1	1499907	2.23	Magnesium	Disc	0.152	0.076		Yes
ACS	Torque Rods	3	33309	0.71	Iron (Core)	Round Tube	0.023	0.495		Yes
C&DH	CTT	1	1497200	3.41	Al 6061	Box	0.179	0.191	0.139	No
C&DH	DPU	1	SAM-0-M-08001	3.30	Al 6061	Box	0.178	0.244	0.146	No
C&DH	RPP	1	50000D02	7.60	Aluminum	Box	0.184	0.286	0.194	Yes
C&DH	Star Coupler	2	5299100	0.71	Aluminum	Box	0.145	0.197	0.042	No
Comm.	Antenna	2		0.07	Fiberglass	Tube	0.025	0.305		Yes
Comm.	S-Band Transponder	1	70-P30001	4.15	Aluminum	Box	0.180	0.281	0.119	Yes
Instrument	HILT Analog Electronics	1	419.104	5.63	Aluminum	Box	0.154	0.450	0.073	Yes
Instrument	HILT Digital Electronics	1	419.108-1	9.60	Aluminum	Box	0.157	0.395	0.157	Yes
Instrument	HILT HV Power Supply	1	419.113-2	0.31	Aluminum	Box	0.085	0.155	0.045	No
Instrument	HILT Instrument	1	419.100-T9-2	7.22	Aluminum	Irregular Box	0.273	0.307	0.224	Yes
Instrument	Isobutane Tank Assy	1	1499787	1.80	Aluminum	Cylinder	0.241	0.398		Yes
Instrument	LEICA Instrument	1	MD-050	7.45	Al 6061	Irregular Boxes	0.396	0.734	0.165	Yes
ACS	Magnetometer Boom	1	1499979	0.27	Al 6063	Square Tube	0.025	0.354	0.025	Yes
Instrument	MAST/PET	1		8.82	Aluminum	Box	0.3048	0.457	0.254	Yes
C&DH	DPU Power Supply	1	SAM-0-M-08001	0.73	Aluminum	Box	0.121	0.132	0.064	No
Power	Battery	1		11.13	Aluminum	Box	0.1666	0.264	0.109	Yes
Power	PD/PCU	1	1499850	2.98	Al 6061	Box	0.146	0.260	0.089	Yes
Power	PSE	1		7.47	Aluminum	Box	0.305	0.457	0.203	Yes
Power	Solar Array Hinge		1499744	0.45	Ti-6AL-4V	Flange	0.044	0.057	0.022	Yes
Power	Solar Panel Assembly	2	1499757	4.68	Composite	Flat Plate	0.368	1.148	0.017	Yes
Structure	Battery Isolator Plate	1	1499697	0.15	Al 6061	Flat Plate	0.185	0.383	0.010	Yes
Power	Battery Radiator Plate	1	1499682	1.27	Al 6061	Flat Plate	0.152	0.292	0.006	Yes
Structure	Battery/CTT Enclosure Frame	1	1499634	0.37	Al 6061	Open Frame	0.411	0.414	0.013	Yes
Structure	Battery/CTT Enclosure Panel	1	1499695	0.10	Al 6061	Flat Plate	0.382	0.412	0.001	Yes
Structure	Battery/CTT Support Plate	1	1499603	0.34	Al 6061	Flat Plate	0.380	0.414	0.010	Yes
Structure	Blank Support Plate	1	1499604	0.21	Al 6061	Flat Plate	0.248	0.380	0.010	Yes
Structure	Bottle Bridge	1	1499616	0.42	Al 6061	Open Frame	0.057	0.239	0.041	No
Structure	Bottom Enclosure Assy	2	1499696	0.04	Al 6061	Bent Plate	0.165	0.414	0.044	Yes
Structure	Bus	1	1499601	1.14	Al 7075	Open Frame	0.261	0.267	0.078	Yes
Structure	HILT Support Frame Assy	1	1499621	0.92	Al 6061	Open Frame	0.414	0.427	0.020	Yes
Structure	HILT Support Plate	1	1499609	0.10	Al 6061	Trough	0.070	0.319	0.029	Yes
Structure	HILT/LEICA Support Plate	1	1499610	2.11	Al 6061	Trough	0.070	0.303	0.116	Yes
Structure	HILT/MAST/PET Support Plate	1	1499611	0.15	Al 6061	Flat Plate	0.061	0.377	0.010	Yes
Structure	Instrument Support Plate	1	1499606	0.53	Al 6061	Flat Plate	0.420	0.581	0.010	Yes
Structure	LEICA Support Plate	1	1499607	1.96	Al 7075	Flat Plate	0.581	0.816	0.006	Yes
Structure	Lower Antenna Mount	1	1499688	0.06	Al 6061	Winged Plate	0.037	0.377	0.064	Yes
Structure	MAST/PET Support Frame Assy	1	1499615	0.92	Al 6061	Open Frame	0.414	0.427	0.026	Yes
Structure	RPP Support Plate	1	1499605	0.21	Al 6061	Flat Plate	0.248	0.380	0.010	Yes
Structure	Sensor Support Plate	1	1499608	1.63	Al 6061	Open Frame	0.581	0.816	0.006	Yes
Structure	Star Coupler Mounting Rod	6	1499761	0.00	SS 303	Rod	0.005	0.087		Yes
Structure	Umbilical Bracket Assy	1	1499776	4.49	Al 5052	Open Box	0.152	0.270	0.165	Yes
Structure	Small Balance Weight	3		1.18	Brass	Slab	0.064	0.076	0.013	Yes
Structure	Large Balance Weight	1		3.76	Brass	Slab	0.102	0.152	0.013	Yes
Power	Battery Cells (inside Battery)	22		0.45	S Steel	Box	0.076	0.095	0.012	Yes

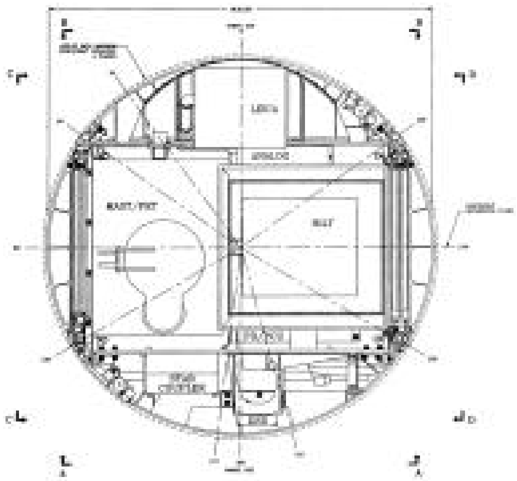

Figure 2. Top and bottom views of SAMPEX. Note the direction designations in the top view.

Figure 3. Views A-A and B-B (respectively) as referenced in the top view above.

Figure 4. Views C-C and D-D (respectively) as referenced in the top view above.

2.3.2 MODELING OF OBJECTS – *SHAPE*

As stated in 2.1.2 it was necessary to model each spacecraft component as either a sphere or a cylinder. The spacecraft was divided into components as identified in the SAMPEX Assembly Drawing (GD1499685) and the overall dimensions of all objects were determined as accurately as possible. Those components for which all three major dimensions were within 20% of the average of the dimensions were modeled as spheres. All other spacecraft components were modeled as cylinders.

The NSS is also very specific about the choice of dimensions for the diameter and length of the cylindrical model. It states: "The longest dimension will be the length (L), and the largest dimension in the transverse direction will be the diameter of the cylinder (D)." Occasionally this requires that a component which most resembles a disk must be modeled as a much larger cylinder. In this case the NSS instruction was followed, resulting in some components with larger surface area (more likely to demise), but with a larger resulting debris casualty area if they were to survive re-entry.

2.3.3 MODELING OF OBJECTS – *MATERIAL PROPERTIES*

The majority of the structural components are constructed of aluminum alloy, as shown on the associated part drawings. The various aluminum alloys were treated separately when the alloy was identified in the part drawing. All unidentified aluminum alloys were assumed to be 2024-

T8XX. Properties for other materials were obtained from reference books and internet searches as necessary. All organic materials (fiberglass/epoxy composite, for example) were modeled using the properties for graphite/epoxy found in the DAS built-in materials database.

DAS contains a materials database of the key parameters for many of the materials commonly used in spacecraft construction. These material properties produce accurate results when used for solid objects but as mentioned previously, DAS cannot model the wall thickness of hollow objects such as boxes, so a simple modification of material properties is necessary to produce satisfactory results. The basic approach is to create a “synthetic” material that has a modified density, specific heat and heat of fusion, but other parameters identical to the parent material. The synthetic material density (also termed the “effective density”) is simply the known or estimated mass of the object divided by its modeled volume. For example, the ACE box which has an aluminum outer shell, has a mass of 4.30 kg and a volume of 0.014 m^3 giving a synthetic material density of 302.3 kg/m^3, compared to the actual density of aluminum of 2803 kg / m^3. The corresponding values for specific heat and heat of fusion are found by multiplying their nominal values by the ratio of the actual to synthetic densities, 302/2803 or 0.108 in this example. A similar approach was used to calculate “synthetic” materials properties for the Instrument and all of the boxes housed within the main bus structure. Material properties for all the materials used in this study are shown in Table 2.

The effectiveness of this compensation method was demonstrated in the Re-entry Survivability Analysis of the Extreme Ultraviolet Explorer (EUVE) Satellite. In the analysis, an MPS box on EUVE was very similar in dimensions and mass to an MPS box on CGRO. The demise altitude for the CGRO MPS box calculated using the ORSAT software configured for the wall thickness of the box, was 71.7 km. The demise altitude for the EUVE box calculated by inputting similar initial conditions into DAS and using synthetic material compensation was 71.5 km.

2.3.4 MODELING OF OBJECTS – *MASS*

The Mass Properties Tables for SAMPEX contains the masses of all major components, many sub-components and even small parts such as the torque rods. However, the masses of some of the items modeled for this analysis had to be calculated or estimated.

2.3.5 INITIAL CONDITIONS/ BREAKUP SEQUENCE

The SAMPEX spacecraft was assumed to begin to break up at an altitude of 78 km, the default value for DAS and as previously mentioned the accepted value for the typical initial breakup altitude for reentering objects. The re-entry trajectory is preprogrammed into DAS.

The order in which the structure was modeled to break-up was somewhat arbitrary. Every attempt was made to follow a logical progression but it is simply not possible to predict if two objects would separate as somewhat intact objects or if the process would cause more massive disintegration. In other cases, parts of one structure also formed parts of another.

Table 2: Materials Database used for Re-entry Calculations

Property	Density	Specific Heat	Thermal Conductivity	Heat of Fusion	Heat of Oxidation	Melting Point
Units	(kg/m3)	(J/kg-K)	(W/m-K)	(J/kg)	(J/kg-O2)	(K)
Al 2024-T8xx	2803.2	972.7	54.64	386,116	34,910,934	856
Al 6061	2710	896	170	386,116	34,910,934	855
Al 7075	2810	960	130	386,116	34,910,934	908
Brass	8410	383.3	116	168,734	0	1173
Gr/Ep	1550.5	879.3	4.92	23	12,305,703	700
Magnesium	1830	1050	73	372,000	0	703
SAMPEX S/C	2278	790.75	54.64	313,890	34,910,934	856
SAMPEX Batt Box	1949	676.3	54.64	268,454	34,910,934	856
SAMPEX Batt Cel	1044.7	65.3	16.2	37,361		1683
SS 303	8000	500	16.2	286,098	0	1683
Titanium	4437	805.2	7.15	393,559	32,480,264	1943

2.3.6 SMALL OBJECTS

The analysis of SAMPEX revealed a large number of items that did not meet the 0.25 m minimum length requirement but nonetheless may have a significant probability of re-entry. Modeling of similar objects made of titanium revealed that many of them are likely to survive re-entry. As the NSS does not specifically address analysis of these small objects, an arbitrary criteria was imposed for SAMPEX. All objects made primarily of metals other than aluminum and larger than 0.05 m (approximately 2 inches) were included in the analysis. Objects composed of primarily organic materials (graphite/epoxy, fiberglass/epoxy, etc.) were only included if the largest dimension exceeded 0.25 m.

The other class of objects selected was those consisting of dense materials with high melting points, which in SAMPEX were titanium, iron and stainless steel. This report provides results for all objects that are known to meet or exceed the 0.25 m limit, which are also known to be or suspected to be made of these materials.

3. RESULTS

The re-entry of SAMPEX was modeled in three stages: as a whole object which re-enters intact, decomposition into 45 spacecraft components, and the detailed further decomposition of the battery box into separate cells.

3.1 RUN 1 – INTACT RE-ENTRY

In accordance with Step 3 in the Method to Assess Compliance with Guideline 7, the SAMPEX spacecraft was modeled as a single object. The cylindrical object (0.30 m diameter x 1.0 m long, 161 kg mass) was entered into DAS 1.0 as both the parent object and the sole object. The material for this analysis was chosen as aluminum Al 2024-T8xx. The spacecraft was found to survive re-entry, producing a debris casualty area of 1.44 square meters. When this analysis was repeated using the effective density approach, the result was the same.

3.2 RUN 2 – BREAKUP OF SAMPEX SPACECRAFT

The spacecraft components identified in Table 1 were analyzed using DAS 1.0, using the shapes, dimensions, and materials shown in Table 2., and an initial breakup altitude of 78 kilometers. Table 2 shows the resulting demise altitude for each component. Because all spacecraft components demised, and none of them survived re-entry, the total debris casualty area using this approach was 0 square meters.

3.3 RUN 3 – BREAKUP OF THE BATTERY ASSEMBLY

The SAMPEX battery assembly is composed of an aluminum box containing 22 rectangular stainless steel cells. The battery box was first modeled as one of the spacecraft components in the previous step, using the effective density approach. The battery assembly was then modeled using the battery box as the parent object and the cells as the individual objects. The initial breakup altitude was input as 65.44 kilometers, from the earlier run. For the sake of simplicity, only a single cell was modeled; multiple identical cells yield the same result. The cells were found to demise at 64.8 kilometers, resulting in no additional debris casualty area.

Table 3: DAS Results for SAMPEX Components

Total Debris Casualty Area.... .00000000 m^2

Object Surface Identification	Object Type	Object Diameter (m)	Object Length (m)	Object Height (m)	Object Mass (kg)	Material Type	Demise Altitude (km)	Casualty Area (m^2)
Spacecraft	Cylinder	0.3	1	0	161	Al 2024-T8xx	77.9647	0
ACE	Cylinder	0.241	0.312	0	4.3	Al 6061	72.1115	0
Reaction Wheel	Cylinder	0.152	0.152	0	2.23	Magnesium	71.407	0
Torque Rod	Cylinder	0.023	0.495	0	0.71	SS 303	68.6859	0
RPP	Cylinder	0.194	0.286	0	7.6	Al 6061	66.7162	0
Antenna	Cylinder	0.025	0.305	0	0.07	Gr/Ep	77.8864	0
Antenna	Cylinder	0.025	0.305	0	0.07	Gr/Ep	77.8864	0
S-Band Xpdr	Cylinder	0.18	0.281	0	4.15	Al 6061	70.2189	0
HILT Analog	Cylinder	0.154	0.45	0	5.63	Al 6061	69.8481	0
HILT Digital	Cylinder	0.157	0.395	0	9.6	Al 6061	65.1112	0
HILT Instrument	Sphere	0.268	0	0	7.22	Al 6061	59.5576	0
Isobutane Tank	Cylinder	0.241	0.398	0	1.8	Al 6061	75.7067	0
LEICA	Cylinder	0.396	0.734	0	7.45	Al 6061	74.54	0
Mag. Boom	Cylinder	0.025	0.354	0	0.27	Al 6061	76.3899	0
MAST/PET	Cylinder	0.3048	0.457	0	8.82	Al 6061	71.051	0
Battery	Cylinder	0.166	0.264	0	11.13	SAMPEX Batt Box	65.4402	0
PD/PCU	Cylinder	0.146	0.26	0	2.98	Al 6061	70.7972	0
PSE	Cylinder	0.305	0.457	0	7.47	Al 6061	71.9532	0
Solar Array Hng	Cylinder	0.044	0.057	0	0.45	Titanium	51.1288	0
Solar Panel	Cylinder	0.368	1.148	0	4.68	Al 6061	76.3786	0
Solar Panel	Cylinder	0.368	1.148	0	4.68	Al 6061	76.3786	0
Battery Isolatr	Cylinder	0.185	0.383	0	0.15	Al 6061	77.8119	0
Battery Radiatr	Cylinder	0.152	0.292	0	1.27	Al 6061	75.1194	0
Batt/CTT Encl 1	Cylinder	0.411	0.414	0	0.37	Al 6061	77.8126	0
Batt/CTT Encl 2	Cylinder	0.382	0.412	0	0.1	Al 6061	77.9647	0
Batt/CTT Supprt	Cylinder	0.38	0.414	0	0.34	Al 6061	77.8125	0
Blank Support	Cylinder	0.248	0.38	0	0.21	Al 6061	77.7746	0
Bottom Enclosur	Cylinder	0.165	0.414	0	0.04	Al 6061	77.9647	0
Bottom Enclosur	Cylinder	0.165	0.414	0	0.04	Al 6061	77.9647	0
Bus	Cylinder	0.261	0.267	0	1.14	Al 7075	75.9948	0
HILT Suprt Fram	Cylinder	0.414	0.427	0	0.92	Al 6061	77.4231	0
HILT Suprt Plat	Cylinder	0.07	0.319	0	0.1	Al 6061	77.6557	0
HILT/LEICA Supt	Cylinder	0.07	0.303	0	2.11	Al 6061	70.5726	0
HILT/MAST Suprt	Cylinder	0.061	0.377	0	0.15	Al 6061	77.497	0
Inst Suprt Plat	Cylinder	0.42	0.581	0	0.53	Al 6061	77.775	0
LEICA Suprt Pla	Cylinder	0.581	0.816	0	1.96	Al 7075	77.4256	0
Lower Ant Mount	Cylinder	0.037	0.377	0	0.06	Al 6061	77.7333	0
MAST/PET Suprt	Cylinder	0.414	0.427	0	0.92	Al 6061	77.4231	0
RPP Support Plt	Cylinder	0.248	0.38	0	0.21	Al 6061	77.7746	0
Sensor Suprt Pl	Cylinder	0.581	0.816	0	1.63	Al 6061	77.5827	0
Star Cplr Mount	Cylinder	0.005	0.087	0	0.01	SS 303	76.8305	0
Umbilical Brckt	Cylinder	0.152	0.27	0	4.49	Al 6061	68.491	0
Sm Balance Wt	Cylinder	0.064	0.076	0	1.18	Brass	70.801	0
Sm Balance Wt	Cylinder	0.064	0.076	0	1.18	Brass	70.801	0
Sm Balance Wt	Cylinder	0.064	0.076	0	1.18	Brass	70.801	0
Lg Balance Wt	Cylinder	0.102	0.152	0	3.76	Brass	68.8788	0

4. DISCUSSION OF METHODOLOGY

Throughout this analysis situations were encountered where it was necessary to make an assumption, or choose between options. The most common situation involved the shape to use for modeling an irregular object. Based on directions given in the NASA Safety Standard, most objects were transformed into cylinders. This transformation often involved severe distortion of the object. The most significant example of this involved the solar panels, which were modeled as much larger cylinders than the actual flat plate shape.

The other common situation involved the estimation of mass. Wherever possible, the mass used for analyzing an object was taken from the mass properties data but if this information was not available it was necessary to estimate the mass. This could be difficult given the extensive machining and complex 3-dimensional nature of many of the objects.

In general, a conservative approach was taken when making assumptions or selecting options. Masses and areas were generally overestimated. In the end, the results seem reasonable. All of the objects demised during re-entry, including the solar array hinges made of titanium. Due to their high melting point and low thermal conductivity titanium components are typically likely to survive. Because the hinges were small, they were found to demise during re-entry.

5. CONCLUSIONS

This report has presented a re-entry debris analysis for the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) spacecraft performed using Debris Analysis Software (DAS) in accordance with NASA Policy Directive NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation, and NASA Safety Standard NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris". From this analysis it is estimated that the SAMPEX spacecraft will generate a maximum debris casualty area of 1.44 m^2 from the survival of the intact spacecraft if allowed to reenter without interference. Analysis of the individual spacecraft components revealed that all of them will demise during atmosheric re-entry, resulting in no debris casualty area. The result of either approach is well within the 8 square meter limit specified in NASA Safety Standard NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris".

ACRONYM LIST

ACE	Attitude Control Electronics
ACS	Attitude Control System
C&DH	Command and Data Handling system
CGRO	Compton Gamma Ray Observatory
CTT	Command Telemetry Terminal
DAS	Debris Analysis Software
DPU	Data Processing Unit
EUVE	Extreme Ultraviolet Explorer
GSFC	Goddard Space Flight Center
HILT	Heavy Ion Large Telescope
HV (HVPS)	High Voltage (High Voltage Power Supply)
JSC	Johnson Space Center
LEICA	Low Energy Ion Composition Analyzer
MAST	MAss Spectrometer Telescope
MB	MegaBytes
MPS	Modular Power Subsystem
NASA	National Aeronautics and Space Administration
NPD	NASA Policy Directive
NSS	NASA Safety Standard
ORSAT	Object Re-entry Survival Analysis Tool
PD/PCU	Power Distribution / Power Control Unit
PET	Proton/Electron Telescope
PSE	Power Supply Electronics
RPP	Recorder Processor Packetizer
SAMPEX	Solar, Anomalous and Magnetospheric Particle Explorer
SMEX	SMall Explorer program